National Aeronautics and Space Administration

Spacecraft Habitable Volume: Results of an Interdisciplinary Workshop

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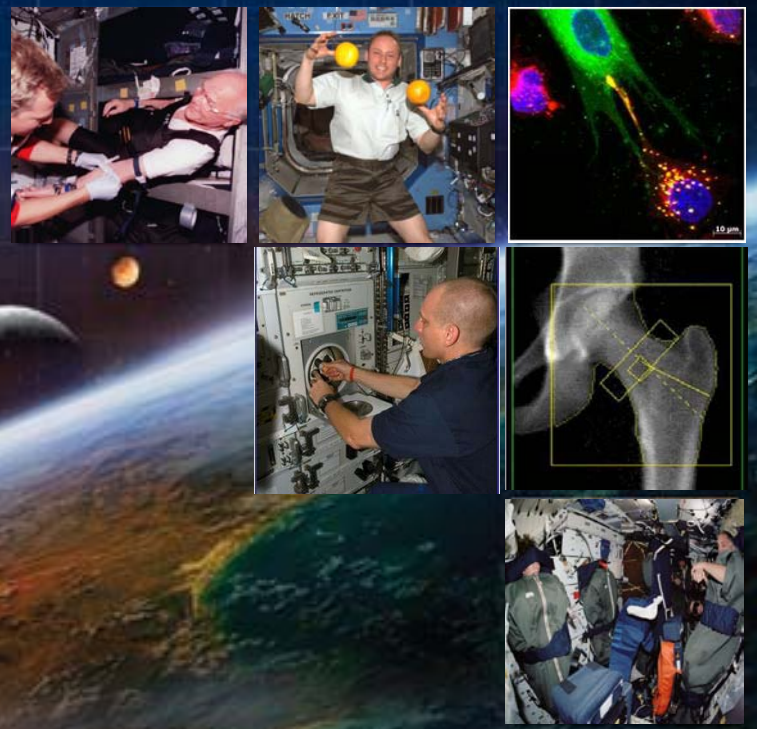

Presentation Outline

- **Description of Net Habitable Volume (NHV) Workshop**
- **Psychological Stressors That Drive Habitable Volume Requirements**
- **Recommendations**
  - Minimal Habitable Volume
  - Further Research

Net Habitable Volume Workshop Description

- **NASA's Human Exploration Framework Team posed the question: "Is 80m^3 per person of habitable volume acceptable for a proposed Deep Space Habitat?"**
  - No experimental data available
  - Decision was made to convene experts to assess current knowledge, and identify forward research strategies
- **Workshop held in Houston, TX, April 18-21, 2011**
- **Participants were from a broad range of disciplines**
  - Anthropology, psychology, human factors
  - Neurology, medicine, physiology
  - Architecture, naval ship building, interior design
  - Personnel experienced in extreme isolation or long duration confinement

Net Habitable Volume Workshop Goals

- **Goal:**
  - Address the “net habitable volume” necessary for long-duration human spaceflight missions
  - Identify design and psychological issues and mitigations
- **Objectives:**
  - Identify psychological factors—i.e., “stressors”—that impact volume and layout specifications for long duration missions
  - Identify mitigation strategies for stressors, especially those that can be written as volume design specifications
  - Identify a forward research roadmap—i.e., what future work is needed to define and validate objective design metrics?
  - Provide advisories on the human factors consequences of poor net habitable volume allocation and layout design

Workshop Planned Products

- **Identification of psychological stressors**
- **Characterization of stressor categories:**
  - Definition
  - Potential mitigation
  - Forward research needs
    - Candidate analog testbeds
    - International Space Station
- **Addendum to existing habitat design standards**
- **Integrated forward research plan**
- **Published report**

Product: Categories of Psychological Stressors (1 of 2)

- **Allocation of space**
  - Feeling of being crowded; Lack of private space
  - Inadequate logistics management and inefficient storage
  - Separation from home
- **Workspace**
  - Boredom; Meaningless work
  - Inadequate design, layout, procedures, equipment
- **General and individual control over the environment**
  - Inability to customize the environment for personal preferences
  - Lack of individual control over environment
- **Sensory monotony**
  - Lack of sensory stimulation
  - Physical monotony, sensory deprivation; Lack of aesthetic design
  - Lack of food freshness and variety

Product: Categories of Psychological Stressors (2 of 2)

- **Social monotony**
  - Social deprivation; Separation from family and friends
  - Limited communications
- **Crew composition**
  - Recruitment and selection; Training
- **Physiological and medical stressors**
  - Inadequate separation/privacy for Hygiene
  - Sleep disruption
- **Contingency**
  - Event preparedness; Ability to plan and support contingencies

Recommendations & Findings: Volume Requirements (1 of 2)

- **Psychological stressor mitigation depends more on layout than on overall internal volume**
  - Through layout design, the same volume can be made to feel "crowded" vs. efficiently utilized
- **A universally applicable volume metric can't be provided**
  - Too dependent on the quality of the layout, mission duration, crew complement, and many other variables
  - Ranges of volume values for scenarios may be achievable
  - "Optimal curve" from NASA-STD-3001 be used as a minimum NHV
- **Habitable volume values for existing spacecraft represent proven solutions for particular durations**
  - E.g., volume is not seen as an issue on the International Space Station, however, there are perceived layout issues
- **Analog environments can help inform research on NHV**
  - E.g., Antarctic habitats, undersea habitats, submarine design, etc.

Recommendations & Findings: Volume Requirements (2 of 2)

- **Developing a Concept of Operations (for a habitat) is essential in determining volume allocation and layout**
- **Research is needed on how scheduling can effectively be used to overlay time-specific single task volumes**
  - E.g., exercise, food preparation & consumption, common areas
- **Mitigation of non-NHV psychological stressors can impact the perception of an allocated volume's acceptability**
  - E.g., Lack of "meaningful work", family problems, etc.
- **Volume and layout design is a multi-disciplinary problem**
  - More emphasis needed on concept of operation and layout analysis
  - Successful volume allocation is a process, not a simple specification

Recommendations: Near-Term Mitigation Strategies

- **Consensus was reached on the following being easily achievable:**
  - Provide a common area to accommodate dining and recreational activities for all crewmembers simultaneously
  - Provide volume to accommodate work activities for all crewmembers simultaneously
    - Might be dissimilar activities that are not co-located
  - Provide individual, private communication capabilities with provisions for noise control
  - Include windows (real or virtual) that provide an immersive, rich sensory experience
  - Design habitat layouts and systems to allow personnel to customize and/or reconfigure their environment
  - Private crew quarters should always be provided

Recommendations: Forward Research

- **Forward work is needed on prioritizing NHV-related stressors and on identifying the human impacts of not considering their mitigation during design**
- **Develop strategies for performing long duration habitation concepts of operations efficiently and effectively**
  - Programs and projects rarely make time to do this well
  - “Con-Ops” inform crew schedules and interior layout analyses
- **Create an analog test bed research plan**
  - Prioritize by importance to habitable volume determination
  - Prioritize by cost
- **Research should address**
  - Perform confinement and isolation studies with durations of the same order of magnitude as desired mission
  - Plan studies using readily reconfigurable volumes and layouts
  - Identify and validate (to analogous missions) the number and types of crewmembers

Backup Charts

BACKUP

Descriptions of Psychological Stressors Impacting Habitat Design (1 of 2)

Psychological Stressor Category	Details
Allocation of Space (H)	**This category deals with the allocation and positioning of certain types of volume to meet psychological needs of the crew.**
Lack of Personal Space / Lack of Private Space	Private and personal space were both identified as highly important to the psychological well being of crew, providing a retreat from social stressors, separation from work areas, a place to interact with family members, and providing a location for personal items.
Feeling of "Crowdedness"	The perceived volume is adversely affected by the increased number of crew "traffic interactions" (which can include the displacement of one crew member to allow for translation of others, or desired simultaneous use of equipment and workstations). Leads to a feeling of inadequacy of the size or layout of the habitat. This stressor can be mitigated by either implementing layout changes or adjusting schedule to reduce forced crew interaction/displacement.
Lack of Privacy of Waste & Hygiene Compartment	Increased privacy of highly personal activities such as crew waste collection and hygiene, contributes to a decrease in intra-crew conflict which could lead to decreased performance.
Workspace (H, L)	**This category addresses the space allocated and workstations designed for meaningful work and activities needed for the psychological health of the crew.**
Lack of Meaningful Work/Activity	A lack of meaningful work/activity during a long duration mission can lead to increased psychological and psychosocial stress, resulting in performance decrements and depression/frustration.
Sense of Poorly Placed Stowage	Poorly placed stowage for performance of tasks can contribute to frustration or other forms of psychological stress
General and individual control of environment (L)	**Control over lighting, airflow,**
Lack of Individual Controls Over Temperature, Ventilation or Lighting	Particularly in crew quarters, anecdotes indicated that insufficient levels of control over personal environment, particularly during sleep, can lead to poor sleep and the associated psychological stressors.
Lack of Reconfigurability for Cultural Difference / Personal Space Preferences	Customize-ability and reconfiguration to best suit needs of the crew can significantly decrease frustration at inflexible spaces.

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Descriptions of Psychological Stressors Impacting Habitat Design (2 of 2)

Psychological Stressor Category	Details
Systems to address sensory monotony (L to M)	**Space and resources should be provided to stimulate cognitive, visual, auditory, tactile, gustatory, olfactory, motor, etc. (L to M - area for plant growth)**
Lack of Stimulation/Sensory Variability	Current missions to the ISS provide a window with a close view of earth, real time communication with loved ones at home, and crew care packages that bring novel items (i.e. fresh fruit) to astronauts throughout the duration of their six month stay. Future long duration missions will not have these countermeasures as a way to mitigate sensory deprivation. Evidence shows that cognitive, visual, auditory, tactile, gustatory, olfactory, motor monotony, as experienced in isolated, confined, and extreme environments, can serve as a chronic stressor to the individual. Also, long term lack of choice and control over work format and leisure can negatively impact mood - this impacts on volume as choice and control necessitate a minimum amount of variety.
Systems to address social monotony (L)	**Resources should be provided to facilitate communication with family and friends**
Social Deprivation / Lack of Common Areas	Lack of group spaces to encourage group activities can result in decreased crew cohesion
Limited Communication with Home	Communication system with family and friends at home
Crew composition (H)	**Number, gender, cultural differences, roles, leadership, relationship, crew selection and training**
Crew composition may be a cross cutting /high level driver/ overarching category which impacts several other stressors in other categories, and can be addressed via other habitat requirements. Input and suggestions are welcome here.	1) Crew number can impact crew dynamics (e.g. potentially higher risk of marginalisation and group dysfunction with 3 crew versus 4 or more) 2) The presence of female crew members amongst predominantly male crews can gave a positive influence on group dynamics - mixed crews may impact design and layout (evidence on female vs. male preferences regarding environment) 3) Crew members of differing nationalities will have different expectations and needs regarding private space, leisure etc
Physiological and Medical Issues (M)	**Includes waste management**
Lack of Hygiene Separation	Separation of dirty-clean areas has a psychological component beyond the functional requirement separating these areas.
Contingency readiness (M)	
Lack of "Backup Plan" / "Rescue Scenario"	Long duration isolation in extreme environments places severe stress on individuals which is magnified by the perception that certain contingencies have been overlooked. This "no escape" perception can be alleviated by providing backup contingencies for every scenario, including loss of a module.

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Research Recommendations (1 of 3)

Psychological Stressor Category	Layout/Implementation Guidance	Research Recommendations
General and individual control of environment (L)		
Lack of Individual Controls Over Temperature, Ventilation or Lighting	Place individual controls and distribution vents in crew quarters and at workstations	- ISS - record use of individual controls of lighting and comments which would lead to expansion of the ranges of control or improvements to current crew quarters design
Lack of Reconfigurability for Cultural Difference / Personal Space Preferences	Reconfigurable packaging for crew accommodations and furniture	- Survey of ISS and other astronauts concerning desire for reconfigurability of outfitting - Usability testing of various reconfigurable outfitting designs - Simulations; Antarctica stations and HDU - Microgravity testing of down selected outfitting at ISS
	Modular design with multiple applicable locations for multiple activities	- Simulations; Antarctica stations
Systems to address sensory monotony (L to M)		
Lack of Stimulation/Sensory Variability	Windows (Provide visual stimulation of high quality close to Earth, but limited utility on long duration transit missions)	- Data mining; assess effects on behavioral outcomes
	Virtual Windows - Camera with projections of space, video of terrestrial footage, telescope,	- Deploy in remote, long duration environments; compare behavioral health outcomes
	"Holodeck" or other virtually immersive environment	- Development and testing in long duration environments, i.e.. Antarctica
	Increased spatial vista within habitat	- Study to characterize the impact of spatial vista on psychological acceptability
	Lighting, colors, and other visual countermeasures to increase sensory stimulation	- Development of systems for spaceflight
	Greenhouse or other introduction of plants and natural elements for tactile, visual, gustatory, olfactory	- Determine to what extent plants address these sensory systems so can develop other CM if these are not sufficient
	Different surfaces in the interior to maintain tactile senses	
	Provision of musical instruments and music selection to counteract auditory	- Interview flyers, others in LDM to identify what works/doesn't work about this and other recreational CM
	Enhance exercise system to include virtual experience	- Development of systems for spaceflight
	Allocation of space for exercise equipment and "stretch-out" room	

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Research Recommendations (2 of 3)

Psychological Stressor Category	Layout/Implementation Guidance	Research Recommendations
Systems to address social monotony (L)		
Social Deprivation / Lack of Common Areas	A common area for recreation, large enough to accommodate all crew members inside at the same time	- Comparison of crew interactions in habitats with variations of group spaces
	Include 'television' (or equivalent) for crew to watch movies together (movies in the form of data can be transmitted from earth to also provide sensory stimulation)	
	A common area for dining, large enough to accommodate all crew members dining inside at the same time. This can be the same as the common area for recreation (converted). Kitchen required for food preparation.	
Limited Communication with Home	Communication system should be provided in each private quarter	
	System that facilitates voice and text should be provided	- Development of systems for spaceflight
	Space for a "holodeck" to provide visual and auditory connection with loved ones at home.	- Development of systems for spaceflight
	Private space with pictures of family members	
Crew composition (H)		
Crew composition may be a cross cutting /high level driver/ overarching category which impacts several other stressors in other categories, and can be addressed via other habitat requirements. Input and suggestions are welcome here.	Characteristics of the crew (team size, gender makeup, job roles, cultural backgrounds) which are established prior to the mission and will not change as a result of the mission should be considered when defining the habitat requirements.	- Data mining (data and anecdotal evidence from space flight and other international agencies) to determine things such as: - if married, then configuration shall ____ - if two males and two females, then configuration shall_____ - if three crew then configurations shall ____
Physiological and Medical Issues (M)		
Lack of Hygiene Separation	Provide separation between clean areas (medical treatment, food prep, crew quarters, etc.) and dirty areas (hygiene, dusty areas, etc.) Medical treatment area may need to be separate as a biological contaminant (dirty) and a sterile (clean) area.	- Implement on future layouts
	Provide olfactory or other partitions to prevent contamination of clean areas. This can include closed, separately ventilated areas.	
Contingency readiness (M)		
Lack of "Backup Plan" / "Rescue Scenario"	Recommendation to have separate modules (recommendation for redundant ships, that are connected; two Orion vehicles with station module in the middle.)	
	Placement of hatches to allow for alternate escape routes. Provision of radiation shelter	

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Research Recommendations (3 of 3)

Psychological Stressor Category	Layout/Implementation Guidance	Research Recommendations
Allocation of Space (H)		
Lack of Personal Space / Lack of Private Space	Provide individual, separate sleeping/personal quarters w/auditory isolation (mandatory) and physical separation (if possible) for each crew member	- Noise abatement - Volume acceptability testing of private crew quarters - Airflow, velocity, temperature of air conditioning system in crew quarters
	Isolated locations throughout the vehicle	- Assess "perceived" personal space and privacy under different layouts
	Separation of private spaces from spaces allocated for common, social areas and congested translation paths is preferred	- Assess "perceived" personal space and privacy under different layouts
	Visual separation of private spaces from each other to allow for perception of increased privacy	- Assess "perceived" personal space and privacy under different layouts
	Rotating shifts	- Assess "perceived" personal space and privacy under different layouts
Feeling of "Crowdedness"	Separation of high traffic function	- Clear definition of operations assumed during mission with detailed schedule could allow for analyses to layout interiors with significantly reduced crew congestion or crew displacement. -Development of scheduling tools that incorporate layout considerations; testing of these scheduling tools
	Appropriate task scheduling/ task location	
	Dedicated translation paths in integrated environment	
	Increased volume or other dimensions to increased actual/perceived space	
	Rotating shifts	
Lack of Privacy of Waste & Hygiene Compartment	Dedicated, private area for waste and hygiene with hygiene areas away from dining area and medical station	- Could potentially determine actual volume # - Determination of # of bathrooms (presumably based on crew size)
	Separation of WHC area from translation areas	
Workspace (H, L)		
Lack of Meaningful Work/Activity	Provide individual development plans for each person's work goals, progress, and achievements	- Determination of the appropriate level of crew autonomy and selection of tasks for greater crewmember satisfaction
	Allocation of space and resources to accommodate each individual's work and activities (i.e. science, laboratory equipment, electronic curriculum, etc...). Each individual should have their own workspace and materials should be appropriately placed for ease of use and improved functionality	- Need list of activities to be performed on long duration missions to inform designers of necessary equipment, crew composition, and scheduling requirements - Develop individualized goals for each crewmember to ensure meaningful activities
	Volume will be needed to hold samples and toolkits for in-flight experiments. Other features to impact volume may include electronic equipment to store data (workstations and hard drives) and a telescope. Equipment needed for analysis of collected samples during inbound flight.	- Systematically assess current NASA processes for providing crew members with hardware and electronic resources. How are these ensured to fit within specific parameters?
Sense of Poorly Placed Stowage	Ensure stowage types are near designated areas (i.e. food near dining)	- Leverage ISS experience with stowage and consider placement for function and performance early in designs
	Ensure that not all materials are stowed in one place	